Paper Title: **Population viability impacts of habitat additions and subtractions: A simulation experiment with endangered kangaroo rats.**

Heinrichs, Julie A.;

University of Calgary, address, jasmit@ucalgary.ca

- Darren Bender, David Gummer, Nathan Schumaker

Species viability is influenced by the quality, quantity and configuration of habitat. For species at risk, a principal challenge is to identify landscape configurations that, if realized, would improve a population's viability or restoration potential. Critical habitat patches emerge from such analyses as features that desirable landscape configurations tend to have in common. We present here a novel approach for identifying critical habitat patches, using Canada's endangered Ord's kangaroo rat (*Dipodomys ordii*) as a case study. Natural habitat for the species consists of actively-eroding sand dunes; however, kangaroo rats also use disturbed sandy areas (typically roadsides) which are hypothesized to be population sinks. Our study employed a spatially explicit population model to integrate information on kangaroo rat habitat quality, quantity, and configuration with survival and reproduction estimates. We then used iterative patch addition and removal experiments to generate estimates of the contribution of individual patches to overall population viability. Results will be presented on the relative roles of habitat quality and quantity in our case study system, as well as the successes and shortcomings of this approach for identifying critical habitat elements.

MODELING THE ROLE OF BEHAVIOR IN WILDLIFE RESPONSES TO LANDSCAPE CHANGE

Joshua J. Lawler, College of Forest Resources, University of Washington, Box 352100, Seattle, WA 98195, phone: 206.685.4367, fax: 206.616.6101, jlawler@u.washington.edu
Nathan H. Schumaker, US Environmental Protection Agency, 200 SW 35th St., Corvallis, OR, 97333, USA. 541.754.4476. schumaker.nathan@epa.gov.

Land-use change alters landscapes at different rates and to different degrees. Wildlife responses to shifting habitat conditions vary from species to species depending on the rate of landscape change, species' life history traits, and aspects of behavior such as dispersal patterns and nest-site fidelity. Here, we explored how these factors together determine the extent to which Willow Flycatchers can track changes in a managed landscape in western Oregon. Using a spatially explicit population model, we simulated flycatcher populations in the Umpqua watershed of the Coast Range in Oregon over a 100-year period. Landscape change reflected current and likely future forest management activities across a variety of land-ownerships. We parameterized the model with known attributes of Willow Flycatcher behavior and life history traits. Despite overall increases in habitat quality, Willow Flycatcher populations were unable to track the rapidly shifting mosaic of suitable and unsuitable habitats, and thus declined steadily. We used the results to explore how rates of landscape change, dispersal ability, nest-site fidelity, and survival rates impact Flycatcher persistence. Although all four factors influenced the population's response to landscape change, nest-site fidelity had a particularly strong effect on the population's response to the shifting habitat mosaic. Our results emphasize the importance of species' behavior in determining wildlife responses to landscape change.

Key words: landscape, population dynamics, modeling, behavior, forest management, birds, simulation

HexSim: A flexible simulation model for forecasting wildlife responses to multiple interacting stressors.

Nathan Schumaker (US Environmental Protection Agency)
Joshua Lawler (University of Washington)
Allen Brookes (University of Washington)

With SERDP funding, we have improved upon a popular life history simulator (PATCH), and in doing so produced a powerful new forecasting tool (HexSim). PATCH, our starting point, was spatially explicit and individual-based, and was useful for evaluating a range of terrestrial life histories, landscapes, and disturbance regimes. But PATCH had significant limitations. It was a single-population females-only model whose individuals were all identical. It had a modern but cumbersome interface, and it could not capture stressor interactions. These limitations compromised the model's realism and utility. In constructing HexSim from PATCH we have relaxed these and many other constraints; HexSim is a true multi-population and multi-stressor program. In addition, HexSim's populations are trait-based, which means individuals can have unique and dynamic properties. Traits can be genetic, probabilistic, or experiential in nature, and they can influence individual vital rates and behaviors. This poster will illustrate the design, features and use of the new (and freely available) HexSim model.

Invited poster at Joint Fire Science Program Extended Poster Session at: 4th International Fire Ecology & Management Congress: Fire as a Global Process. 30 November - 4 December 2009, Savannah, Georgia.

Assessing the compatibility of fuel treatments, wildfire risk, and conservation of Northern Spotted Owl habitats and populations in the eastern Cascades

*Rebecca S.H. Kennedy[1], Alan A. Ager[2], Paul F. Hessburg[3], John F. Lehmkuhl[4], Bruce G. Marcot[5], Martin G. Raphael[6], Nathan H. Schumaker[7], Peter H. Singleton[8], and Thomas A. Spies[9]

[1]Research Ecologist, USDA Forest Service, Pacific Northwest Research Station, Corvallis Forestry Sciences Laboratory, Oregon, USA. [2]Operations Research Analyst, USDA Forest Service, Pacific Northwest Research Station, Western Wildlands Environmental Threat Assessment Center, Oregon, USA. [3]Research Ecologist, USDA Forest Service, Pacific Northwest Research Station, Wenatchee Forestry Sciences Laboratory, Washington, USA. [4]Research Wildlife Biologist, USDA Forest Service, Pacific Northwest Research Station, Wenatchee Forestry Sciences Laboratory, Washington, USA. [5]Research Wildlife Biologist, USDA Forest Service, Pacific Northwest Research Station, Portland Forestry Sciences Laboratory, Washington, USA. [6]Research Wildlife Biologist USDA Forest Service, Pacific Northwest Research Station, Olympia Forestry Sciences Laboratory, Washington, USA. [7]Landscape Ecologist, US Environmental Protection Agency, Environmental Research Lab, Oregon, USA. [8]Ecologist, USDA Forest Service, Pacific Northwest Research Station, Wenatchee Forestry Sciences Laboratory, Washington, USA. [9]Research Forester, USDA Forest Service, Pacific Northwest Research Station, Corvallis Forestry Sciences Laboratory, Oregon, USA.

Land managers are faced with a conundrum when tasked with maintaining populations of the threatened Northern Spotted Owl (NSO: *Strix occidentalis caurina*) while reducing wildfire risk in dry, fire-prone forests of the inland northwest. The USDI Fish and Wildlife Service Final Recovery Plan (FRP: recently remanded) for the Northern Spotted Owl augments the Northwest Forest Plan (NWFP) late-successional reserves and calls for development of dynamic, shifting mosaics in dry forests, with retention of late successional reserves in moist forests of the eastern Cascades of Oregon and Washington. However, the desired spatial allocations and temporal dynamics have not been determined.

We are developing and evaluating several management scenarios in the Okanogan-Wenatchee and Deschutes National Forests of eastern Washington and Oregon intended to conserve NSO habitat and reduce fire risk at stand and landscape scales. Our study is unique because it focuses not only on fire and fuels management effects on NSO habitat, but also on NSO populations, and influences of the Barred Owl (BDOW) on the NSO.

Our objectives are to: 1) quantify and map current large wildfire risk to NSO habitat and the spatial pattern of risk with respect to existing forest structure; 2) determine short-term effects of management compatible with the NWFP and local forest plans; and 3) characterize long-term potential dynamics in distribution of NSO habitat and populations under various fuel management and conservation design scenarios, for policymakers and managers. Our work provides innovative modeling procedures and results, maps showing areas most prone to large wildfires, examples of landscape vegetation and fuels management prescriptions to minimize likelihood of the largest fires, and maps and modeling predictions of habitat dynamics and probability of NSO persistence under different scenarios.

Rebecca S.H. Kennedy
Research Ecologist
USDA Forest Service
Pacific Northwest Research Station
Forestry Sciences Laboratory
3200 SW Jefferson Way
Corvallis, OR 97331
Phone: (541) 750-7262
Fax: (541) 750-7329
Email: rebeccakennedy@fs.fed.us
or rebeccakennedy@oregonstate.edu

Julie Heinrichs, Darren Bender, Nathan Schumaker

The Relative Effects of Habitat Loss, Fragmentation, and Degradation on Population Extinction

The most prominent conservation concerns are typically habitat loss and habitat fragmentation. The role of habitat degradation has received comparatively little attention. But research has shown that the quality of habitat patches can significantly influence wildlife population dynamics, suggesting that habitat degradation may be a key variable explaining population responses to landscape change and disturbance. We conducted a simulation modeling study to determine the relative influence of habitat quantity, fragmentation, and quality on regional population persistence. We adopted a life history strategy approach stratified by dispersal ability and resource requirements. Population dynamics were simulated in landscapes which varied in their degree of habitat loss, fragmentation, and habitat degradation according to a factorial design. Population dynamics were evaluated using a spatially-explicit individual-based computer simulation model. Landscape configurations ranged from contiguous to highly fragmented. The importance of habitat quantity, fragmentation, and quality for population persistence was evaluated using generalized linear models. For the most part, habitat amount and quality outweighed the influence of habitat fragmentation. Dramatic extinction thresholds were observed in scenarios that combined habitat loss and degradation, indicating that the interactive effects of these variables may greatly affect population persistence. The results also suggest that in some circumstances the population viability consequences of habitat loss might be effectively mitigated through improvements to habitat quality. While the current paradigm for conservation emphasizes the role of habitat fragmentation, our results demonstrate that habitat quality may at times be of greater importance.

Assessing critical habitat: Evaluating the relative contribution of habitats to population persistence

JULIE A. HEINRICHS[1], Darren J. Bender[2], David L. Gummer[3], Nathan H. Schumaker[4]

[1] Department of Biological Sciences, University of Calgary, 2500 University Drive NW Calgary, Alberta, T2N 1N4; j.a.heinrichs@gmail.com
[2] Department of Geography, University of Calgary, 2500 University Drive NW Calgary, Alberta, T2N 1N4; dbender@ucalgary.ca
[3]Parks Canada, Western and Northern Service Centre. 1550-635 8 Avenue SW Calgary, Alberta, T2P 3M3
[4]Western Ecology Division, U.S. EPA. 200 SW 35th St. Corvallis, Oregon, USA 97333

A principal challenge of species conservation is to identify the specific habitats that are essential for long-term persistence or recovery of imperiled species. However, many approaches to identifying important habitats do not provide direct insight into the contribution of habitats to population persistence. To assess how habitats contribute to overall population viability and characterize their relative importance, a spatially-explicit population viability model was used to integrate a species occurrence model with habitat quality and demographic information to simulate the population dynamics of the Ord's kangaroo rat in Alberta, Canada. Long-term productivity (births-deaths) in each patch was simulated and iterative habitat removal experiments generated estimates of the relative contribution of habitat types to overall population viability. Both methods provided the basis for prioritizing habitats for conservation. Our approach was particularly useful for identifying habitats that did not contribute to population viability. 39% of habitat represented sinks and their removal increased estimated population viability. This approach can be invaluable when assessing critical habitat, particularly in regions with variable habitat quality. Approaches that do not incorporate population dynamics may undermine conservation efforts by under- or over-estimating the value of habitat patches, erroneously protecting sink habitats, or failing to prioritize key source habitats.

Spatially Explicit Population Modeling and the Reintroduction of a Native Ungulate: Using HexSim to Evaluate Release Alternatives

Huber, PR
University of California, Davis
prhuber@ucdavis.edu

Schumaker, NH
U.S. Environmental Protection Agency
schumaker.nathan@epa.gov

Greco, SE
University of California, Davis
segreco@ucdavis.edu

Hobbs, J.
California Department of Fish and Game
JHobbs@dfg.ca.gov

The tule elk (Cervus elaphus nannodes), a subspecies of ungulate endemic to central California, was nearly brought to extinction in the 19th century and is still extirpated from most of its natural range. As part of an ongoing restoration program, we evaluated a portion of its former range in the Central Valley for potential reintroduction of a free-ranging herd. We used a new spatially explicit population model (HexSim) to analyze four different elk release scenarios. Each scenario corresponded to a different release location, and the model was used to compare simulated elk population dynamics 25 years into the future. We also used HexSim to identify likely locations of human-elk conflict. Population forecasts after the 25-year period were highest (mean female population size of 169.6 per iteration) and potentially harmful barrier interactions were lowest (mean 8.6 per iteration) at the East Bear Creek site. These results point to the East Bear Creek site release scenario as the most likely to result in a successful elk reintroduction. We found HexSim to be a very useful tool for this type of reintroduction planning and believe that it will prove to be successful for other conservation planning studies as well.

Landscape resistance to dispersal: predicting long-term effects on a small and isolated wolf population in southwestern Manitoba, Canada

Astrid V. Stronen, Nathan H. Schumaker, Graham J. Forbes, Paul C. Paquet, and Ryan K. Brook.

Landscape fragmentation affects wildlife population viability, in part through the effects it has on individual dispersal. Considerable fragmentation of native habitats and loss of forest cover has occurred in association with agricultural development over the past 50 years in our study area - the region surrounding Riding Mountain National Park (RMNP) in southwestern Manitoba, Canada. However, some forms of human disturbance impinge on dispersal without simultaneously fragmenting habitats. In this study, we examined how protected area boundaries, roads outside the protected area boundaries, and hostile human behaviour have altered dispersal success without simultaneously fragmenting habitat. We simulated dispersal using HexSim, a spatially-explicit individual-based population model, parameterized with data on wolves (*Canis lupus*) in the RMNP region. Scenarios that accounted for negative human attitudes and roads outside the protected area boundaries exhibited lower mean population size than scenarios that ignored these details. In contrast, increasing deflection from protected area boundaries did not appear to have a significant consequence for population viability. Our results illustrate how habitat fragmentation itself can fail to account for the impacts on wildlife imparted by some forms of dispersal barriers.

ABSTRACT

The HexSim Model

Nathan H. Schumaker

EPA is now completing version 2.0 of the HexSim model. HexSim took three years to complete. It grew out of EPA's PATCH model. HexSim is a spatially-explicit, individual-based, multi-species computer model designed for simulating terrestrial wildlife population dynamics and interactions. HexSim is very general, with landscapes, life histories, disturbance regimes, and most other details being supplied by the user at run-time. HexSim also employs a sophisticated graphical user interface. HexSim incorporates GIS representations of real landscapes. The model makes extensive use of spatial data to capture landscape structure, habitat quality, stressor distribution, etc. The model's design makes it ideal for exploring the cumulative impacts of multiple stressors.

Features presently built into the HexSim model include:

- ability to simulate a wide range of life histories
- ability to work with multiple interacting species and stessors
- incorporation of multiple dynamically changing landscapes
- simulation of social structures such as flocks or nesting colonies
- simulation of dynamic territory and range formation and maintenance
- incorporation of environmental stochasticity
- simulation of the impacts of barriers such as roads
- simulation of landscape genetics including mutation
- ability to model differential mortality during dispersal
- ability to exchange data with ESRI software

Contact: Nathan Schumaker, Western Ecology Division, NHEERL. 541-754-4658
schumaker.nathan@epa.gov

HexSim: A flexible simulation model for forecasting wildlife responses to multiple interacting stressors

Nathan Schumaker, Joshua Lawler, Allen Brookes

With SERDP funding, we have improved upon a popular life history simulator (PATCH), and indoing so produced a powerful new forecasting tool (HexSim). PATCH, our starting point, was spatially explicit and individual-based, and was useful for evaluating a range of terrestrial life histories, landscapes, and disturbance regimes. But PATCH had significant limitations. It was a single-population females-only model whose individuals were all identical. It had a modern but cumbersome interface, and it could not capture stressor interactions. These limitations compromised the model's realism and utility. In constructing HexSim from PATCH we have relaxed these and many other constraints; HexSim is a true multi-population and multi-stressor program. In addition, HexSim's populations are trait-based, which means individuals can have unique and dynamic properties. Traits can be genetic, probabilistic, or experiential in nature, and they ca influence individual vital rates and behaviors. This poster will illustrate the design, features, and use of the new (and freely available) HexSim model.

Potential population-level effects of land-use change and climate change

Joshua J. Lawler, Betsy Bancroft, Nathan H. Schumaker

Climate change and land-use change are poised to be two fo the largest drivers of biological changeover the next century. We explored the potential effects of these two forces on a population of Red-cockaded Woodpeckers (*Picoides borealis*) at Fort Benning in Georgia, USA. We used a spatially explicit population-modeling platform, HexSim, to simulate population responses to 1) climate-driven changes in habitat availability and reproductive output, 2) the development of additional troop training facilities, and 3) the current age structure and early senescence of pine forests on the base. Climate change, at least in terms of its effects on habitat and on behaviorally mediated aspect of reproduction, had relatively little affect on simulated populations. In contrast, populations showed strong negative responses to increased development on the base and the aging of the pine forests. Our results indicate that alternative development strategies and intensive forest management practices have the potential to off-set the population declines that will likely result from development and forest aging

A spatially and temporally explicit, individual-based, life-history and productivity modeling approach for aquatic species

Kristina McNyset, Jeff Falke, Chris Jordan, Allen Brookes, Nathan Schumaker

Realized life history expression and productivity in aquatic species, and salmonid fishes in particular, is the result of multiple interacting factors including genetics, habitat, growth potential and condition, and the thermal regime individuals experience, both at critical stages and throughout development. Individual fishes, each with their inherited propensities and characteristics, experience spatially and temporally specific conditions throughout their lives that influence growth, movement, and life history "decisions". Modeling the interaction of these factors at the (potentially) broad spatial and temporal scales at which individuals carry out their life histories is a challenge. There are individual-based modeling approaches which are not spatially-explicit (or limited to restricted and specific spatial domains), spatially-explicit models that are not individual-based, and "spatially-explicit", individual-based models that neglect or simplify the temporal specificity of spatially-explicit conditions. HexSim is a spatially-explicit, individual-based, multi-species computer model designed for simulating terrestrial wildlife population dynamics and interactions. HexSim treats space as a series of continuous hexagonal grids that individuals experience and interact with over discrete time steps. The individual-based modeling modules in HexSim are robust and allow for detailed parameterization of individuals, populations, and events. We are presenting a modification of HexSim for aquatic populations. The unique spatial constraints of stream system modeling, and modifications to the simulation model necessary for inclusion of relevant aspects of fish biology and behavior, will be discussed. Our initial goal is to predict life history expression and production of steelhead (*Oncorhynchus mykiss*) in the John Day River basin, Oregon. Spatially and temporally continuous parameter datasets (e.g. water temperature and food availability) developed for the John Day will also be presented.

Modeling Wildlife Populations With HexSim

HexSim is a framework for constructing spatially-explicit, individual-based computer models designed for simulating terrestrial wildlife population dynamics and interactions. HexSim is useful for a broad set of modeling applications including population viability analysis for one or more wildlife species, studying the consequences for wildlife of multiple interacting disturbances, assessing which habitat components are most critical for population maintenance, quantifying the consequences of species invasions or competition, designing restoration, mitigation, or reintroduction strategies, determining the impacts that roads and other barriers may be having on viability, measuring the consequences for wildlife of changes to landscape connectivity, exploring mechanisms linking human activities to patterns of disease spread, adding realism to the study of landscape genetics, and more.

One of HexSim's most salient features is the use of traits in describing individual characteristics. HexSim traits are defined at the population level, but implemented on an individual basis. HexSim's traits can be used to control most life cycle events using trait combinations to stratify outcomes. In addition, trait values can be influenced by multiple other traits, making it possible to set up stressor interactions and complex feedback loops. Traits can also be used to capture species' interactions such as parasitism, competition, mutualism, breeding, and so on.

HexSim provides many data analysis tools including reports, output maps that illustrate model dynamics, and an animated simulation viewer. In addition, the HexSim Census events can be used to track population size, stratified by any combination of traits. Other usability-related features include a batch processing tool, a sensitivity analysis module, and more.

This talk will provide an introduction to the features and uses of HexSim using a simplified predator prey example.

Adding Biological Realism to Assessments of Landscape Connectivity

Nathan H. Schumaker
Allen Brookes
US Environmental Protection Agency
200 SW 35th Street
Corvallis, OR 97333

Researchers have long appreciated the practical value of connectivity and source-sink analyses. The importance of these assessments for conservation, planning, and reserve design has motivated many empirical and simulation studies. But there are few modeling tools available that can identify demographic sources and sinks on a landscape. And methods being used to quantify landscape connectivity tend to balance tractability against biological realism. Linkages between connectivity and source-sink models, and greater biological and ecological realism are both needed before landscape connectivity studies can contribute fully to land management. Here we illustrate how a new spatially-explicit population model (HexSim) can be used to simultaneously evaluate source-sink dynamics and landscape connectivity. What most significantly distinguishes our approach is that source-sink dynamics and connectivity are emergent properties of HexSim simulations. The analysis does not require that landscapes be decomposed into habitat patches, or that sources, sinks, or dispersal corridors be identified in advance. Fluxes may be tracked between arbitrary locations such as political or ownership units. HexSim quantifies source and sink strength, and it computes probabilities that individuals will move between locations. We illustrate how this methodology can be used to quantify the importance of individual landscape features for region-wide population distribution and viability. As HexSim is a freely available, and very general modeling framework, this new technology should be useful to a wide audience.

A new tool that links landscape connectivity and source-sink dynamics to population viability

Nathan H. Schumaker
Allen Brookes
Julie A. Heinrichs

The importance of connectivity and source-sink dynamics to conservation planning is widely appreciated. But the use of these concepts in practical applications such as the identification of critical habitat has been slowed because few models are designed to identify demographic sources and sinks, and popular methods for quantifying landscape connectivity tend to forgo realism in favor of tractability. Better linkages between connectivity and source-sink models, and greater biological and ecological realism are needed before landscape connectivity-based studies can more fully contribute to conservation planning. Here we illustrate how a new spatially-explicit population model (HexSim) addresses these challenges. HexSim is a versatile multi-species, multi-stressor life history simulator that can account for landscape change, road networks, landscape genetics, disease dynamics, and many other practical concerns. What distinguishes our new methodology is that source-sink dynamics and connectivity become emergent properties of HexSim simulations. It is not necessary to limit biological or ecological realism, to decompose landscapes into nodes or patches, or to identify sources, sinks, or dispersal corridors in advance. In this presentation, we will use a range-wide simulation of the Northern Spotted Owl (*Strix occidentalis caurina*) to illustrate the model and methodology, and to tie our landscape connectivity metrics to the identification of critical habitat.

HexSim – A General Purpose Framework for Spatially-Explicit, Individual-Based Modelling

HexSim is a framework for constructing spatially-explicit, individual-based computer models designed for simulating terrestrial wildlife population dynamics and interactions. HexSim is useful for a broad set of modeling applications. This talk will focus on a subset of those applications, including multiple, interacting stressors, population interactions, landscape genetics, and the newest HexSim feature, aquatic population dynamics.

Graph-based analysis of connectivity in spatially-explicit population models: HexSim and the Connectivity Analysis Toolkit

Authors: Carlos Carroll, Klamath Center for Conservation Research, Orleans, CA and Nathan H. Schumaker, US EPA, Corvallis, OR

Background / Question / Methods

Planning for the recovery of threatened species is increasingly informed by spatially-explicit population models. However, using simulation model results to guide land management decisions can be difficult due to the volume and complexity of model output. This is especially true when simulated movement data is used to evaluate landscape connectivity. To better understand the management significance of simulated dispersal processes, we applied graph-theory-based metrics to transform dispersal data into mapped features that could directly inform planning (for example predicted linkage areas). We focused in particular on two forms of centrality, a group of metrics that consider paths between all possible pairwise combinations of nodes in a graph in order to evaluate the role of each in mediating the flow of dispersers across a landscape. Our study examined both shortest-path betweenness centrality and PageRank (a variant of eigenvector centrality) through the application of these metrics to a graph derived from dispersal events simulated in a HexSim model of the Northern Spotted Owl in the Pacific Northwest.

Results / Conclusions

Shortest-path betweenness centrality identified a network of important linkages, comprising habitat that was frequently used for dispersal. PageRank identified key patches whose importance derived from the observation that dispersers originating from those sites colonized other sites that in turn produced many additional dispersers. We use the insights gained from this analysis to illustrate how a habitat network composed of important linkages and key patches can be used to guide reserve design efforts that seek to conserve population connectivity.

RECENT DEVELOPMENTS IN COMPUTER MODELING ADD ECOLOGICAL REALISM TO LANDSCAPE GENETICS

Authors: White, Schumaker, Brookes, McRae

Background / Question / Methods

A factor limiting the rate of progress in landscape genetics has been the shortage of spatial models capable of linking life history attributes such as dispersal behavior to complex dynamic landscape features. The recent development of new models such as Circuitscape (McRae et. Al. 2008. Ecology 10:2712-2724), CDPOP (Landguth and Cushman, 2010, Mol. Ecol. Resour. 10:156-161), and UNICOR (Landguth et. al. 2012, Ecography 35:9-14), is ameliorating this problem, but the discipline's long term growth will require tools that capture the additional ecological realism necessary to perform management-relevant forecasting, and work quantitatively with adaptive genetic traits. Here. we look at the short and long term computational needs of the discipline, and ask to what extent current modeling tools will be able to meet these demands.

Results / Conclusions

Our background research suggests that the principal focus of work in landscape genetics today involves neutral markers and hindcasting, with a goal of illustrating how current allele distributions might be explained by landscape features. The need to develop management strategies that ensure species' viability in the midst of climate change, invasive species, habitat loss, and other anthropogenic disturbances will force landscape geneticists to do more forecasting, and to incorporate interacting stressors into their models. We illustrate an approach for doing just this using the recently developed HexSim model, which includes a landscape genetics toolkit. Our HexSim example involves a simulated predator-prey system in which the benefits of prey capture efficiency impart a selective pressure upon the predator genome. We use this example, and preliminary results from our own research, to illustrate how advances in simulation model development might assist landscape genetics in meeting the practical challenges the future is sure to hold.

Modeling population response to anthropogenic threats for a long-lived reptile, the desert tortoise

Michael W. Tuma, Chris Millington, Nathan Schumaker, and Paul Burnett

Background/Question/Methods

The decline in desert tortoise population densities and abundances since the 1970s has been attributed to numerous threats, leading scientists, land managers, and conservationists to describe the plight of the species as a "death by a thousand cuts." Because the desert tortoise is threatened by so many anthropogenic stressors, and because the distributions and severity of these threats vary in time and space, the challenge of determining species' management priorities is daunting. Further, because the desert tortoise is long-lived, has delayed sexual reproduction, and has long generation times, it is difficult for field-based studies to mechanistically link population response to the presence or absence of specific threats. We have attempted to overcome these difficulties through use of the HexSim population modeling software. HexSim makes it possible to examine single threats in isolation, and multiple threats in concert, to determine their individual and combined effects on populations.

Results/Conclusions

We developed a predictive habitat model that describes the potential for occurrence of desert tortoises based on the occurrence of importance habitat elements within the Gold Butte-Pakoon tortoise conservation area, located in southern Nevada and northwestern Arizona. We used this habitat model in HexSim, where we linked it to rules governing tortoise movement and population density. We obtained information on vital rates and movement behaviors from field studies and existing literature on the species. After developing a baseline tortoise model, we added threats (human presence, subsidized predators, grazing livestock, and wildfire) to evaluate population responses, and to prioritize the importance of each threat in limiting tortoise population growth.

Previous population models developed for turtle and tortoise species have determined that increased adult mortality, particularly of females, was the most influential factor limiting population growth. However, these models could not account for spatial variance in threat number or intensity. Our spatially-explicit model determined that threats with a widespread distribution were much more important in limiting population growth than those that were patchily-distributed over a limited area. Moreover, our results suggest that threats that cause habitat degradation over a broad area, such as livestock grazing and illegal off-road vehicle use, could be more important contributors to desert tortoise population decline than patchily distributed threats that cause mortality alone, such as the presence of subsidized predator populations or road mortality. These results challenge previous assumptions pertaining to desert tortoise population management, and set the stage for a re-evaluation of management priorities.

USING HEXSIM TO SIMULATE COMPLEX SPECIES, LANDSCAPE, AND STRESSOR INTERACTIONS

Authors: Schumaker, Brookes, Carroll, Huber, Nogeire, Singleton, Tuma, Wilsey, Xie

Background / Question / Methods

The use of simulation models in conservation biology, landscape ecology, and other disciplines is increasing. Models are essential tools for researchers who, for example, need to forecast future conditions, weigh competing recovery and mitigation strategies, or evaluate the consequences of stressor interactions on one or more populations. On the other hand, model development is often time-consuming, costly, and limited by access to computer programmers. These constraints slow innovation, and they slow scientific progress. This symposium will highlight research advances made possible by recent developments in individual-based population modeling. Speakers in this symposium will, in part, describe work that has been conducted using a particularly flexible model named HexSim. This presentation will introduce the HexSim model, and will provide illustrations of its structure and use drawn from ongoing research.

Results / Conclusions

Using HexSim, we have developed a diverse range of simulation models that account for multiple species and stressor interactions, weigh possible recovery and reintroduction strategies, examine disease spread in an individual-based and spatially-explicit context, track changes in population genotypes over large spatial and temporal scales, and quantify landscape connectivity. Results from these studies will be used to illustrate how simulations models that are spatially-explicit, individual-based, and trait-based are advancing research in conservation biology, landscape ecology, and other disciplines.

USING HEXSIM TO ASSESS POTENTIAL REINTRODUCTOIN SITES FOR A NATIVE UNGULATE

Authors: Huber, Schumaker, Greco, Hobbs

Background, questions, methods

The tule elk (*Cervus elaphus nannodes*), a subspecies of ungulate endemic to central California, was nearly brought to extinction in the 19th century and is still extirpated from most of its natural range. As part of an ongoing restoration program, we evaluated a portion of its former range in the Central Valley for potential reintroduction of a free-ranging herd. We used a new spatially explicit population model (HexSim) to analyze four different elk release scenarios. Each scenario corresponded to a different release location, and the model was used to compare simulated elk population dynamics 25 years into the future. We also used HexSim to identify likely locations of human-elk conflict, the major cause of elk mortality in California's tule elk herds. These sources of conflict were: urban areas, roads, and concrete-lined canals. We varied the maximum dispersal distance to test the sensitivity of the model to uncertainty surrounding this parameter, running each scenario three times using different values.

Results, conclusions

Population forecasts at the four sites after the 25-year period ranged from a mean of 84.2 (females only) to 169.4. Mean barrier interactions per iteration per site ranged from 8.6 to 2,837.5. Populations were highest and potentially harmful barrier interactions were lowest at the East Bear Creek site. Conversely, populations were lowest and barrier interactions dramatically highest at the Kesterson site. These relationships held regardless of the maximum dispersal distance used. These results point to the East Bear Creek site release scenario as the most likely to result in a successful elk reintroduction. Changes in maximum dispersal distance had minimal effects on resulting population and barrier interaction numbers. We found HexSim to be a very useful tool for this type of reintroduction planning and believe that it will prove to be successful for other conservation planning studies as well. HexSim enabled us to rank management scenarios and to identify more likely future locations of detrimental human-elk interactions. The herd movement component of HexSim was especially critical for this study.

Impacts of habitat loss, climate change and pesticide exposure on kit fox populations

Theresa Nogeire, Josh Lawler, Nathan Schumaker, Brian Cypher and Scott Phillips

Background / Question / Methods

The San Joaquin kit fox is an endangered sub-species in decline due primarily to loss of habitat. This small, desert-adapted fox was once widely distributed across the floor of the southern San Joaquin Valley, but agriculture and development have replaced much of the species' habitat. In addition to pressure from continued habitat loss, the kit fox faces pressure from climate change. High precipitation in habitats now dominated by non-native, annual grasses leads to dense, tall growth that is unsuitable for both the kit fox and its primary prey, kangaroo rats. Conversely, persistent dry conditions lead to low primary productivity that cannot support kangaroo rats, and results in a corresponding decline in kit fox populations. Finally, kit foxes using human-dominated landscapes are exposed to anticoagulant rodenticides, which have adverse effects in individuals but unknown effects on fox populations.

Results / Conclusions

We modeled the cumulative impact of land-use change, climate change, and hypothetical rodenticide exposure scenarios on kit fox populations using HexSim, a new life history simulator that is particularly well-suited for investigating stressor interactions. Our study indicates that land-use change will likely create larger impacts than pesticide exposure, and climate effects will depend in part on uncertain precipitation projections. Our study illustrates how recent advances in individual-based population modeling have made it possible to study off-target pesticide impacts while explicitly addressing real-world complexities such as habitat fragmentation, climate change, and species interactions.

INTEGRATING SPECIES DISTRIBUTIONAL, CONSERVATION PLANNING, AND INDIVIDUAL BASED POPULATION MODELS: A CASE STUDY IN CRITICAL HABITAT EVALUATION FOR THE NORTHERN SPOTTED OWL

Authors: Jeffrey R. Dunk, Brian Woodbridge, Nathan H. Schumaker, Betsy Glenn, Dave LaPlante, and Brendan White

Background / Question / Methods

As part of the ongoing northern spotted owl recovery planning effort, we evaluated a series of alternative potential critical habitat scenarios using a species-distribution model (MaxEnt), a conservation-planning model (Zonation), and an individual-based population model (HexSim). Our approach was designed to permit a comparison of estimated owl population responses to multiple hypothetical habitat conservation scenarios. Each scenario represented a different set of assumptions regarding critical habitat size/spatial arrangement, trends in relative habitat suitability, and barred owl impacts. A total of 98 "what if" scenarios were evaluated using HexSim, and the results were used to forecast relative spotted owl population responses to the candidate conservation strategies.

Results / Conclusions

Based on our HexSim model results, we were able to recommend a critical habitat network that, in our estimation, would allow spotted owl populations to become stable (rather than the currently-estimated decrease), remain well-distributed throughout their current range, and would keep the population resilient in spite of future uncertainty regarding habitat trends and barred owl impacts. Our recommended critical habitat network is more efficient than most of the alternative candidate scenarios we evaluated. The modeling framework we developed and used, in particular our methods for the application of HexSim, should be readily transferrable to other reserve planning studies. Finally, our study illustrates a method for quantifying the relative risk of alternative conservation scenario design decisions while there is still flexibility in the planning process.

The development of a spatially-explicit, individual-based, disease model for frogs and the chytrid fungus

Gisselle Yang Xie, Nathan Schumaker, Allen Brookes and Andrew Blaustein

Background / Question / Methods

The fungal pathogen, *Batrachochytrium dendrobatidis* (BD), has been associated with amphibian population declines and even extinctions worldwide. Transmission of the fungus between amphibian hosts occurs via motile zoospores, which are produced on the infected host and released into the water column to further encyst on new hosts. Although fungi are conventionally considered microparasites, experimental and field research has demonstrated that BD also exhibits macroparasitic characteristics. Critically, the consequences of BD infection are highly dependent on the number of zoospores present on the host. While a number of models have been formulated for the investigation of the population-level epidemiology of BD, Cheryl Briggs and colleagues have developed the only model to date that addresses the dose-dependency properties of these particular fungal infections. But the Briggs model is non-spatial and has limited ability to explain the dynamics of the BD epidemic at landscape scales. Here we describe a spatially-explicit analog to the Briggs model that we have developed using HexSim.

Results / Conclusions

We constructed a model for the dispersal of *Batrachochytrium dendrobatidis* (BD) throughout a hypothetical metapopulation of a generic aquatic Ranid amphibian using HexSim, a spatially-explicit, individual-based simulation framework. Our study investigates how likely BD is to invade and persist endemically within a population based on host reproductive rate, duration of the larval life stage, and types of hypothesized dispersal vectors. Our spatially-explicit model also illustrates how landscape features influence the spread of the disease, and it facilitates the exploration of large scale mitigation strategies.

MODELING INTERACTIONS BETWEEN SPOTTED OWL AND BARRED OWL POPULATIONS IN FIRE-PRONE FORESTS

Authors: Singleton, Marcot, Lehmkuhl, Raphael, Kennedy, Schumaker

Background / Question / Methods

Efforts to conserve northern spotted owls (Strix occidentalis caurina) in the eastern Cascades of Washington must merge the challenges of providing sufficient structurally complex forest habitat in a fire-prone landscape with the limitations imposed through competitive interactions with a recently established population of barred owls (Strix varia). Barred owl individuals tend to displace spotted owls from optimal habitats, and from established nesting sites. We used HexSim to develop a northern spotted owl population model that could simultaneously address the effects of both changing habitat structure and barred owl distribution. Our model allowed us to examine likely future spotted owl population trends within the Okanogan-Wenatchee National Forest, Washington.

Results / Conclusions

We used HexSim to quantify spotted owl population size, dispersal patterns, the spatial distribution of births and deaths, and other metrics, both with and without barred owl interactions. The influence of barred owls led to substantial differences in both the size and distribution of the simulated spotted owl population. We are also using our population model to evaluate conservation strategies for northern spotted owls in fire-prone forests using a management-focused multi-model framework that carefully captures the interactions between forest management strategies, forest growth rates, and the risk of high intensity wildfire.

The Design and Implementation of Eco-Evolutionary PVA Models: An Integrative Approach Using HexSim

Allen Brookes
Nathan H. Schumaker
Jennifer M.W. Day

To persist into the future, species of conservation concern must remain both demographically and genetically viable. Developing mitigation and recovery strategies to ensure species' viability necessitates the use of forecasting models that can incorporate ecological and/or evolutionary processes. Of the available models commonly used for forecasting population dynamics, few are both spatially-explicit and individual-based, and there are fewer still that merge ecological and evolutionary processes. But the speed and extent of species and habitat loss has pushed the long-standing need for eco-evolutionary models into the forefront of PVA research. We demonstrate how an eco-evolutionary modeling tool, HexSim, can improve PVA by linking demography and genetics. HexSim is a spatially explicit, individual-based life history simulator that uses a flexible trait-based approach to associate multiple dynamic attributes with simulated individuals. This modeling approach simplifies the simulation of multiple-stressor interactions as well as adaptive (or neutral) genetic traits. We illustrate how this flexible, eco-evolutionary scheme is implemented, demonstrate its application to PVAs with HexSim example simulations, and discuss how it could be adopted for use in other model development efforts.

Integrating Distributional, Spatial Prioritization, and Individual-Based Models to Evaluate Potential Critical Habitat Networks: A Case Study Using the Northern Spotted Owl

Jeffrey R. Dunk, Dept. Environmental Science and Management, Humboldt State University, Arcata, CA
Brian Woodbridge, United States Fish and Wildlife Service, Yreka, CA
Nathan H. Schumaker, United States Environmental Protection Agency, Corvallis, OR
Elizabeth M. Glenn, United States Fish and Wildlife Service, Oregon Fish and Wildlife Office, Portland, OR
David W. LaPlante, Natural Resource Geospatial, Yreka, CA
Brendan White, United States Fish and Wildlife Service, Oregon Fish and Wildlife Office, Portland, OR

As part of the northern spotted owl recovery planning effort, we evaluated a series of alternative critical habitat scenarios using a species-distribution model (MaxEnt), a conservation-planning model (Zonation), and an individual-based population model (HexSim). With this suite of modeling tools, we were able to quantify simulated spotted owl population responses to multiple realistic (but hypothetical) conservation scenarios. Each scenario represented a different set of assumptions regarding critical habitat size/spatial arrangement, trends in relative habitat suitability, and the severity of barred owl impacts. A total of 98 such hypothetical conservation scenarios were evaluated using HexSim, and the results were used to inform the US Fish and Wildlife Service's critical habitat designation process. Simulated spotted owl population size, spatial distribution, and extinction risk were the parameters used to rank the alternative scenarios.

We were able to identify specific conservation scenarios that, assuming a reduction in barred owl impacts, would stabilize future spotted owl population numbers while preserving their distribution throughout the majority of their current range. The modeling framework we developed, in particular our methods for the application of HexSim, should be readily transferrable to other reserve planning studies. Finally, our study illustrates how to quantify the relative risk of conservation scenario design decisions while there is still flexibility in the planning process.